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Miscellaneous and Electronic Loads Energy Efficiency Opportunities for Commercial Buildings: A Collaborative Study by the United States and India

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1. Introduction

This report documents the technical evaluation of a collaborative research, development, and demonstration (RD&D) project that aims to address energy efficiency of Miscellaneous and Electronic Loads (MELs) (referred to as *plug loads* interchangeably in this report) using load monitoring and control devices. The goals of this project are to identify and provide energy efficiency and building technologies to exemplary information technology (IT) office buildings, and to assist in transforming markets via technical assistance and engagement of Indian and U.S. stakeholders. This report describes the results of technology evaluation and United States–India collaboration between the Lawrence Berkeley National Laboratory (LBNL), Infosys Technologies Limited (India), and Smartenit, Inc. (U.S.) to address plug-load efficiency. The conclusions and recommendations focus on the larger benefits of such technologies and their impacts on both U.S. and Indian stakeholders.

Since 2009, LBNL has conducted collaborative activities with Infosys to develop a smart plug strip that can monitor and perform intelligent control of individual outlets via a wireless and sensor network. The current technology platform allows building managers and occupants to monitor and control plug loads from their computers or handheld devices. Any enhancements through this technical evaluation of plug-load technologies would make the plug strip a hub for office environmental monitoring and control (e.g., temperature, lighting). Infosys has funded their internal product development costs and provided cost-share for this study. For the project described in this report, LBNL tested and evaluated the plug-load monitors and controllers and provided feedback to Infosys on the design and user interface and on the energy-efficiency impacts.

1.1 Benefits to the United States and India

This project is intended to improve energy efficiency of MELs through development of a hardware and software platform, working with both U.S. and Indian vendors. We utilized the IT strengths of both countries, i.e., capabilities in software services and wireless metering and control technologies. Miscellaneous and electronic loads are a rapidly growing end use in commercial buildings in both the U.S. and India, but are the least studied for energy-efficiency improvements due to the lack of data and availability of cost-effective technologies.

1.2 Leveraged Collaborative RD&D

In this project, LBNL and Infosys collaborated to develop a smart power strip to reduce energy use of MELs. Infosys is developing smart power strip software to monitor and control plug loads, which in the future may serve as a hub for a workstation-focused automation system. Infosys is working with the U.S. companies that provide hardware capabilities to their software platform. Such synergies will improve the U.S.–India bilateral collaboration for joint development of clean energy technologies.

2 Background

The U.S.–India Energy Efficiency Technology Cooperation Conference in 2009 focused on clean energy collaboration between the U.S. and India, which was emphasized in the U.S.–India Partnership to Advance Clean Energy (PACE 2012). Few would argue that the U.S. and India lead the world in the area of IT and software services, and that IT deployment in buildings holds large potential to increase MELs energy efficiency in both new construction and retrofits. In the past, collaborations between LBNL and Infosys have led to multiple technology developments, including improved capability of Energy Plus[1] (U.S. DOE 2012). Additional collaborations in improving energy efficiency in commercial buildings would further address energy-efficiency issues found in both the U.S. and India.

One area of great interest is the monitoring and control of MELs, which in India are claimed to be consuming up to 70 watts per square meter (W/m^2) (0.7 watts per square foot [ft^2]) with long, often multi-shift days. A best-practice guide published by LBNL suggested that this number could potentially be reduced to 7.5 W/m^2 at peak load, through best practices implemented in best-in-class commercial buildings in India (Singh et al. 2013). A plug-load study for a commercial U.S. office building also concluded that computer management and timer-controlled plug strips had the potential to reduce energy use by 150 and 75 megawatt-hours (MWh) per year, respectively, which translate into roughly 12 percent and 6 percent of energy consumption in the study building (Lansizera et al. 2011). These past studies indicate the much potential exists to significantly reduce plug-load energy use in both India and the U.S., through device-level monitoring and control.

Miscellaneous and electronic loads are also a growing concern in the U.S.; they consume about 20 percent of the primary energy used in commercial buildings, and this end use is projected to increase by 40 percent in the next 20 years (U.S. DOE 2009). Miscellaneous and electronic load energy use in certain federal laboratory buildings, such as LBNL building 90, which was used in this technology evaluation, is likely higher, and in the range of 60 percent (Marini et al. 2011).

Figure 1 shows the energy intensity of the primary end uses in the U.S. commercial buildings sector, such as heating, ventilation, and air conditioning (HVAC); lighting; water heating; refrigeration; and cooking. These traditional end uses are projected to decrease or remain the same from 2010 to 2035, while MELs energy intensity is projected to increase. This is partly because energy-efficiency research and deployments have focused on the traditional end uses in the past two decades. At the same time, the rapid market penetration of consumer electronics has expanded the MELs category significantly; however, the energy use and reduction strategies for the MELs have so far received little attention.

[1] EnergyPlus is a whole-building simulation program to model energy (analysis and thermal load) and water use.

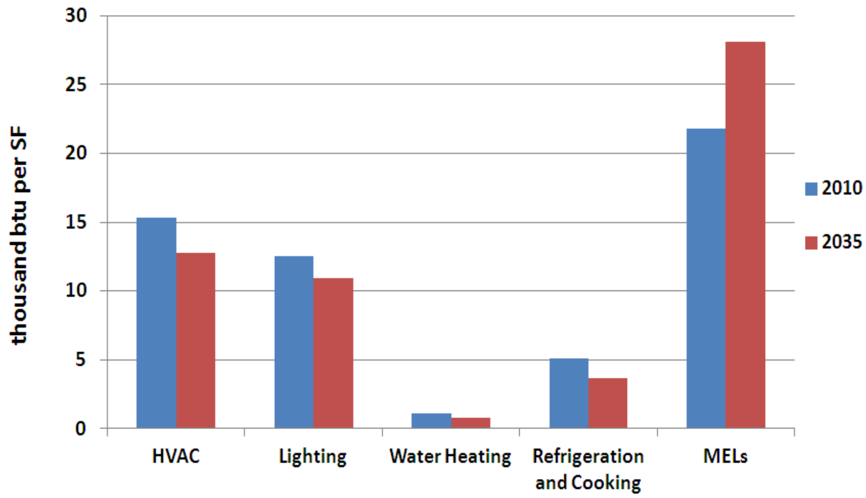

Figure 1. Energy Intensity of Commercial Electricity End Uses, 2010 and 2035

(*Source: U.S. EIA Annual Energy Outlook 2012*)

Energy use of MELs is also spread across many devices and product categories, and usage is often closely tied to users' activities and behaviors, which poses challenges in developing effective and scalable energy-efficiency strategies.

One potentially effective method in reducing MELs energy use is the monitoring and control of individual MELs devices. Under this concept, an instrument with monitoring and control capability would measure the power and energy usage of a specific MEL and control its operating schedule based on pre-programmed user input. The system would provide a direct user-feedback interface, such that the user could assess how much power and energy the device consumes at a particular time, and an operating schedule could be set up to turn down or off unused devices during off-work or unoccupied hours. If properly designed, this monitoring and control system would generate substantial energy savings by turning off/down unused devices. The data collected through power and energy monitoring also have the potential to fill the data gap needed to devise more-effective energy-reduction policies geared toward MELs.

2.1 The System for Energy Efficiency of MELs

With the advances in technology in recent years, a number of research-grade and commercial-grade wireless power meters are now available to monitor MELs on the device level. One such example is the Infosys wireless monitoring and control system evaluated in this project. Figure 2 below shows the architecture of the Infosys Plug Load Manager (PLM) solution, which is used to measure energy consumption and control MELs (Infosys 2012). The PLM solution consists of components, smart plugs, sensor aggregator gateways, a PLM server, and a PLM application. The connectivity between gateway and smart plug is wireless, using the ZigBee communication protocol.

For the study, Infosys provided the PLM software and dashboard platform; Smartenit provided the "smart plugs (also called *plug-load meters*)" (Smartenit 2012), which were connected to MELs in offices using gateways provided by Digi (2012).

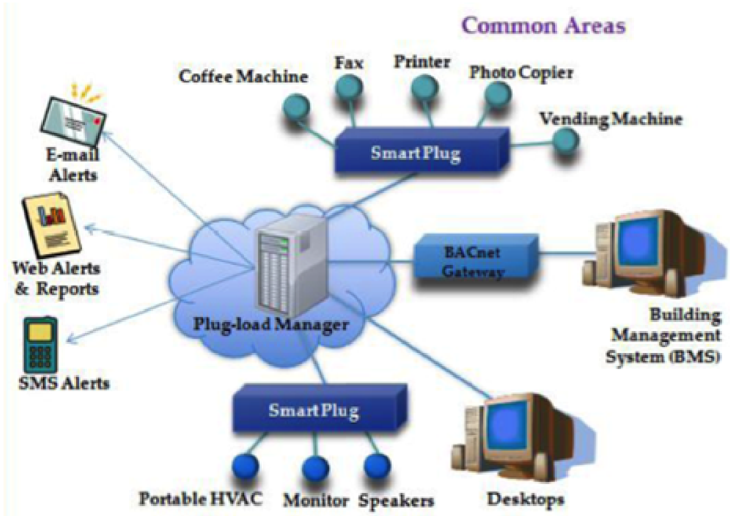

Figure 2. Infosys Plug Load Manager System and Smart Plug Architecture

2.1.1 Features of Plug Load Managers

The Plug Load Manager (PLM), an energy management solution developed by Infosys, can measure energy consumption of plug-in devices. It helps users understand: a) usage beyond preset conditions; and b) energy consumption patterns of plug-in devices over a period of time or during work and non-work hours. The PLM can enable control or reduce energy consumption of plug-in devices through application of automated policies based on time limits, usage limits, peak-load limits, or custom policies. The PLM provides a centralized dashboard for unified monitoring and control of a variety of MELs.

The PLM has additional features: identifying energy consumption by non-critical applications during peak hours, and comparing energy consumption of plug-in devices against industry benchmarks and are described in detail in the below section to describe the capabilities. However, these were not part of this technology evaluation.

2.1.2 PLM Feature Characteristics

The PLM features a variety of characteristics to manage energy consumption:

Derive energy consumption patterns: The PLM allows building managers to measure the energy use of plug-in devices and derive energy use patterns on an hourly, daily, weekly, and monthly basis. From these patterns, it is possible to identify wasted energy.

Policy-driven monitoring and control: Custom energy management policies can be applied remotely to control energy use of individual plug-in devices across the building operations. Policies can be set on the basis of time limits, usage limits, and peak-load limits.

Anywhere, anytime monitoring and control: The PLM can be remotely monitored and controlled from a web-based monitoring station. A mobile phone application is available for anywhere, anytime monitoring.

Unified monitoring and control of plug-in devices: The PLM dashboard allows unified and centralized monitoring and controlling of plug-in devices deployed across buildings in multiple locations. The user can drill down to a specific country, city, building, floor, and zone or device level to view energy use information.

Alerts, notifications, analysis, and reporting: Based on energy use information gathered from plug-in devices across the network, the PLM can trigger text or e-mail alerts or notifications to pre-designated users about abnormal conditions such as excessive energy use, breach of pre-set policies, etc. Users can generate energy use reports at various levels, such as country, city, building, floor, zone, and device.

2.2 Previous System Evaluation by LBNL

The collaboration with Infosys started as a development of smart plug strip to monitor and control individual outlets using a wireless network. The users monitored and controlled plug loads from their computer or handheld devices. LBNL was to evaluate the technology and provide feedback on the design and user interface to make the plug strip a hub for office environmental monitoring and control (e.g., for temperature and lighting). In recent developments, recognizing the strength in software services, Infosys partnered with the U.S. vendors to integrate their software with plug-load meters and different wireless network platforms, thus providing an integrated system for plug-load efficiency.

Before the Infosys system evaluation, LBNL research staff had the experience of working with a wireless power metering system, called the AC Meter (ACme), which was developed by the University of California (UC) Berkeley (Jiang et al. 2009). One of the major differences between the ACme and Infosys' system is that the ACme cannot control devices, and did not have a user control interface. In addition, while the ACme system employs a mesh network, in which individual meters form a communication network and eventually transmit data packets back to an edge router and then the Internet, the Infosys system used for this evaluation uses a star topology. With the star topology (shown in Figure 2), each meter communicates with its assigned gateway individually, thus the required distance between each meter and the gateway is shorter.

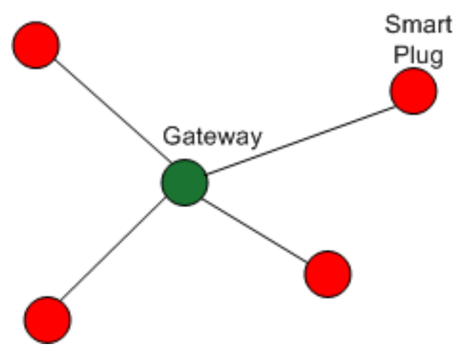

Figure 2. Star Topology Schematic

With inventory of all the MELs in Building 90, and installation of 450 Acmes (about 10 percent of all inventoried MELs), which were subsequently left in place for metering over a period of 6–16 months, we have extensive experience working with wireless power monitoring systems. We were therefore able to apply lessons learned from the ACme deployment to the Infosys technical evaluation, to identify the advantages and potential modifications needed to improve the Infosys system.

3 Study Methodology

Through the deployment and monitoring of the ACme wireless metering system, LBNL was well positioned to install, test, and evaluate the plug-load monitoring technologies. We first installed and commissioned the hardware and software components received from Smartenit and Infosys. This included identifying the test devices, and installing 5 gateways and 39 plug-load meters (or smart plugs), in LBNL Building 90 (B-90) offices as a test bed. The plug-load meters monitored and controlled 7 devices. LBNL sought technical guidance from Smartenit and Infosys to install metering connections and the user interfaces for monitoring and control of MELs. Once the entire system was set up, it was operational in the field for six weeks, which aligned with the project duration and available resources. During this time, LBNL monitored system connectivity, evaluated the control interfaces, and verified the measured data. The technology evaluation and findings are documented in this report.

4 Technology Evaluation

The technology evaluation involved a comprehensive evaluation of the installation and commissioning process for the smart plug system in LBNL B-90. It was an iterative process between LBNL and Infosys staff to understand network connectivity, technology and communications architecture, user interfaces, energy data verification, and monitoring and control strategies. Infosys provided the iSmart energy management system, and its associated software and hardware. The following section covers the details relevant to the objectives of this study, which include installation and commissioning, system architecture, user interfaces, and monitoring and control strategies. Relevant technical recommendations are included here; whereas, the broader observations and recommendations are provided in later sections.

4.1 Installation and Commissioning

Four gateways and 15 smart plugs were deployed in LBNL B-90. As shown in Figure 3, B-90 is primarily an office building with four floors and a basement.

Figure 3. LBNL Building 90 (the test bed for technology evaluation)

Initial deployment happened in June 2012. During this installation stage, 2 gateways and 15 smart plugs were installed. One gateway and 4 smart plugs were deployed in an office located on the second floor of B-90; all devices were located in close proximity of each other within three feet apart, with minimal obstructions in between. Another gateway and multiple smart plugs were deployed in three different office areas on the third floor of B-90, and a number of smart plugs deployed in each office areas. The three office areas used for evaluation were about 10 feet apart from each other in a parallel fashion.

The devices that were metered are listed in Table 1; other device information (manufacturer date and, if available, rated power) was recorded as part of the inventory.

Table 1. Summary for Smart Plug Test Devices

End Use	Category	Product Type	Device Description	Manufacturer	Product Model #
Electronics	Computer	Computer, integrated-LCD	24"	Apple	N/A
Miscellaneous	Lighting	Light, compact fluorescent, dimmable	Berkeley Lamp		N/A
Electronics	Imaging	Multi-function device, laser	Printer	HP	LaserJet 8150DN
Miscellaneous	Commercial Kitchen Equipment	Water cooler, bottle, hot and cold	N/A	Oasis	N/A
Miscellaneous	HVAC	Fan, portable	12"	AirKing	9150K
Miscellaneous	Lighting	Light, compact fluorescent, dimmable	Berkeley Lamp	N/A	N/A
Electronics	Display	Computer display, LCD	27" - also powers 13" MacBookPro laptop	Apple	N/A
Miscellaneous	Lighting	Light, fluorescent	36" under-cabinet	N/A	N/A
Electronics	Computer	Computer, notebook	14"	Dell	N/A
Electronics	Audio	Radio, CB		Motorola	N/A
Miscellaneous	Lighting	Light, fluorescent	T8 - 18" - 15W (2 of them)		N/A
Electronics	Display	Computer display, LCD	24"	Samsung	SyncMaster T240
Electronics	Computer	Dock, notebook	for 14" notebook	Lenovo	N/A
Miscellaneous	Lighting	Light, compact fluorescent, dimmable	Berkeley Lamp	N/A	N/A
Miscellaneous	Laboratory	Laboratory, other	Oscilloscope	Agilent Technologies	DSO-X 2014A

4.2 Network Connectivity and Communications Architecture

The gateway and associated smart plugs in one second-floor office worked properly. However, the gateway and meters in third-floor had partial connections because, the gateway in these three offices had too many smart plugs associated with it, and therefore could not establish reliable connections with all 11 smart plugs. To improve reliability of communications, two additional gateways were installed, such that each office had its own gateway. The lack of reliable communication was primarily due to the use of the star topology network, which requires parings with the gateway for communications. The generic PLM architecture is shown earlier in Figure 2.

4.3 User Interfaces for Monitoring and Control

Although the network connectivity improved after the installation of additional gateways; however, a few smart plugs still had problems connecting to their associated gateways. Identifying the source of the problem required careful evaluation of plug-load meter connectivity with the gateways. A web interface tool (iDigi™) was deployed, in which gateway and meter connection status could be viewed, and various commands could be sent to the gateways. Ultimately it was determined that two smart plugs were faulty. The network connectivity was established after we switched the original smart plugs with two new ones. About a month after the initial deployment, all gateways and meters were still working. In addition to the iDigi web interface, Infosys provided the Plug Load Manager (PLM) interface, where users could view power statistics (instantaneous power), time-series energy plots, and the on/off status for all devices connected to the smart plug network. The PLM was also designed to be a control tool, for devices to be turned on or off remotely with a click of a button.

Although not part of the scope, this monitoring was integrated into the existing LBNL B-90 energy information system (EIS) and installed to improve the building's energy efficiency and comfort (Kircher et al. 2010). The motivation for this was that such a system provides a single interface to different levels of users to monitor overall building energy, including the MELs.

4.4 User Interface Evaluation and Energy Measurement Verification

In addition to displaying instantaneous power measurements for individual devices, the PLM also records and displays energy measurements. The user is given three time-based options to view energy statistics for the given device:

1. today and yesterday
2. last 7 days
3. last 30 days, shown in energy as kilowatt-hours (kWh) versus time (either in hours or days, depending on the time option selected)

For Option 1 (today and yesterday), from reading the energy statistics, the y-axis appeared to be displaying power in kilowatts (kW) rather than energy in kilowatt-hours as labeled on the plot. For Options 2 and 3, although plot labels are shown as energy in kilowatt-hours versus time, the values displayed did not appear to be cumulative kilowatt-hours over the period of time indicated. Infosys should verify the validity of data labels and plotted data. Furthermore, data statistics take a long time to appear on the page, and that could be improved upon. Below the data plots there is a small table indicating working hours, energy consumption, and wasted energy, which appears to be energy consumed outside of working hours. There did not appear to be an option for the users to input their actual working hours; it would be useful to add such a feature and a note on the page instructing how the user can set up their work hour duration.

To verify energy use, we checked the measurements for one notebook computer and one computer monitor, against the measurements taken using another WattsUp Pro™ power meter for the same two devices. Both sets of measurements agreed well, but the individual devices' energy plots could be improved for readability and clarity. The current PLM interface could be improved to read the energy measurements.

4.5 Energy Monitoring and Control Strategies

A main feature of the smart plug system is user access to the monitoring and control interfaces. Two methods are available for device control through the PLM interface:

1. based on time, in which the user can set up when the target device should turn on and off for a specific period of time;
2. based on usage, in which the device would shut off itself after a user-specified energy consumption (in kilowatt-hours) has been met.

After testing the control features with the smart plugs on the network, several improvements are possible. Currently, a control schedule has to be set for an individual meter; an option should be added for a user to set the same schedule for multiple devices. In addition, meters are labeled by their MAC IDs,[2] whereas the PLM interface labels meters by their device numbers. To simplify referencing of deployed meters in the PLM interface, it should show the MAC ID or both the MAC ID and device number.

For the *time-based* control policy, we suggest adding a weekend policy to accommodate different weekday and weekend usage patterns. Currently, only one time-based schedule is allowed and repeated every day of the week.

5 Observations and Recommendations

This section summarizes the observations worth noting from approximately 2.5 months of actual deployment of the smart plug load-monitoring and control system, and the specific recommendations aimed at improving usability and robustness of the system.

5.1 Meter Indicator Lights

One of the instruction guides indicated that a "fastest flashing" versus a "fast flashing" light indicator on the smart plug carries different meanings, but the difference is too fine for the user to distinguish. In addition, if technically possible, a light on the meter indicating whether a connection is established between a smart plug and its associated gateway would be a very useful addition, so that the user does not have to log into the web interface to obtain this information.

[2] MAC ID or Media Access Control Address is unique network identification number assigned to a networked communication device.

5.2 Gateway and Meter Communication

As discussed earlier, our initial deployment on the third floor of B-90 was not successful because there were too many smart plugs (11) and they were located too far away for this version of gateway design (10–15 ft). Commercial offices in the U.S. usually have at least three MELs per individual office or cubicle, with fairly high occupant density to maximize space use. Therefore, systems capable of longer communication range and able to handle the loads of at least a few dozen meters would be much more efficient and practical for large-scale deployment.

In addition to the limited range, based on the conversation with Infosys and observations, the smart plug wireless system might be prone to high attenuation due to common obstructions in the office environments, such as cubicle separations and concrete walls. Improvement to this current feature would result in a more robust and flexible system.

5.3 Gateway/Meter Reset and iDigi Interface

The gateway and smart plug resets performed by LBNL staff involved unplugging and re-plugging the entire system and going onto the iDigi interface to execute an "enable join" command, to instruct the target gateway to accept smart plug connections. After performing such steps, from our experience, it could take a few hours for the smart plugs to connect to the gateway, which can be frustrating to the user and delay the troubleshooting process if the reset attempt proves to be unsuccessful.

A couple LBNL setups required multiple resets to restore or establish gateway/meter connections. Furthermore, there were times when we had to reset (unplugged and re-plugged) all the meters associated with a gateway because of a single non-communicative meter, and that resulted in a lower number of overall smart plugs connected to the network, because some smart plugs were unable to associate with the gateway after the reset. As a result, we recommend that there be a method to reset only the non-communicative smart plug(s) but not all smart plugs associated with a gateway. In addition, we recommend that improvements be made on the iDigi interface speed.

The current implementation is time consuming on the user to scale the deployments. It is recommended that the reset steps be simplified, especially given the more limited technical support available to the average user, compared to the attention that LBNL staff were able to get during this testing phase.

5.4 Plug Load Manager (PLM)

On the PLM interface, the instantaneous power displayed should be expressed in watts, rather than kilowatts, because of the limited power draw of the common office devices being metered, and because the smart plug is only rated at 1.5 kW. For example, if a florescent task light draws a power of 40W, it would be shown as 0.0 kW on the PLM interface, even though it should be expressed as 0.04 kW. Based on the evaluation of the PLM interface described in Section 4 of this report, we recommend verification of the validity and usefulness of energy measurement/monitoring plots. We also recommend that the option to extract and download the numerical power and energy data be added to the PLM. Finally, energy pricing is assumed to be $1 per kilowatt-hour on the PLM interface; this pricing should either reflect the actual energy price charged in the building, or it be entered by the user.

5.5 Network Connectivity and Notification System

During the LBNL deployment, the building occupants inadvertently unplugged a gateway; a situation that went unnoticed probably for days. Subsequently, all associated smart plugs were disconnected from the network during this period of time. Based on our experience, we recommend that a communication system be set up such that the user would be notified if a gateway or meter were disconnected from the network for an extended period of time, to prevent unintended outages of the smart plug system.

5.6 Monitoring and Control through the PLM Interface

The Infosys system currently has two mechanisms for device control: (1) timer-based control, and (2) usage-based control. Both require the input of a start date and end date. We recommend that a master/slave-type control mechanism be considered as a third option, in which the power states of a primary device dictate the power states of its logically grouped devices. An example would be when a computer is turned off; the displays and speakers connected to it would also be switched off to save energy. This mechanism would require both logical grouping and using power as an input to a control algorithm, but it would be applicable to many device types in the office environment. Such enhancements to the plotting and data viewing/monitoring capabilities could significantly improve the control and user feedback features.

5.7 Overall System Performance

The smart plug system contains features for plug-load monitoring, control, and demand-response,[3] which are useful functions to address plug-load energy use reduction. However, the system that was tested, including the gateways, meters, and software interfaces, could be improved to become a more user-friendly system. There are already limited incentives for occupants in commercial office space to save plug-load energy. Such a system can be expanded to set corporate- or building-level policies with additional functions to support occupant monitoring and controls. Any system that can sustain user participation needs to be robust and sufficiently simple to use.

From our experience deploying the smart plug system, and through technical recommendations described earlier in this report, the wireless system can benefit from improvements that will enable it to:

- be more suitable for commercial deployment.
- provide reliable communication and network connectivity.
- handle many meters per gateway and have a long distance range and communication less prone to attenuation due to common office obstructions.
- include a user-friendly interface and reduced steps to detect and perform system resets and reduced software interfaces (e.g., both iDigi and PLM).

Fortunately, the improvements in networking communications such as mesh will allow the robustness in network connectivity. The other improvements in software and user interfaces can be attained through further testing and development.

6 Conclusion and Next Steps

[3] In this study, LBNL did not test or evaluate the demand-response functions.

The rapid growth in economy and new construction markets in India create new concerns for the energy consumption of MELs. Because MELs are a shared issue in the U.S. and Indian buildings, and both countries are leaders in the information technology field, collaborative development of technologies to reduce MELs energy issue will benefit both countries and improve building energy efficiency. The areas for improvements recommended in Section 5 will improve robustness and user adoption of the system. Device-level monitoring and control software require continual user participation and reliable network communication technologies and hardware. With proper technology development and appropriate collaboration with the U.S. and Indian partners, we can realize this potential. These conclusions are focused on improving energy efficiency of MELs in commercial buildings, and facilitating collaboration between the U.S. and India.

In this project, the U.S. and Indian vendors developed the wireless plug-load control system, capable of recording power and energy use of connected MELs and applying a pre-programmed operating schedule to reduce their energy use. The system is complemented with a software and user interface from Infosys that provides information feedback and intelligent control. With support from Infosys and LBNL's experience and understanding of wireless communications and metering systems for commercial and residential facilities, the team was able to undertake a technical evaluation on the technology and provide feedback to improve the robustness of the overall system. The final goal is a monitoring and control system for MELs that is robust, easy to install and maintain, and that encourages continual occupant participation to significantly reduce MELs energy use. Further technology development would then enable the product to be extended to an integrated office hub, which could control other environmental factors such as temperature and lighting, to further reduce energy use in commercial buildings. In this technology evaluation, LBNL determined that the Infosys software system has the potential to reduce MELs energy use at the device level.

6.1 MELs Energy-Efficiency Opportunities in Commercial Buildings

A significant opportunity for energy efficiency in MELs is the information technology systems (e.g., computers), which are responsible for most of MELs energy use in office buildings. The intelligent power management capabilities such as PLM system can be used to reduce their energy use. Power management can be used to power-down MELs based on (1) user input, and (2) periods of inactivity and network-based power management initiated by network inactivity or remote server controls.

Since computers are usually linked to peripherals, such as external hard drives, monitors, printers, and external speakers, powering-down computers can allow these peripherals to also enter low-power states. Information technology power management could benefit from information collected in the integrated office hub, like occupancy data to improve power management decisions. Computer power management is expected to save half of desktop computer energy use if fully deployed in the United States. The computer being the "master" of its peripherals leads to the concept of a smart power strip that exercises master-slave control, in which the peripherals on the designated "slave" outlets would disconnect from power, if the "masters" (the computers) were shut off. Other control schemes include occupancy-based, timer-based, and network-based controls. The

Infosys' PLM system is an excellent example of this power management tool for MELs that holds high potential for energy savings.

Research also suggests that widespread use of such smart power strips in office buildings could be used to save one-third of the non-computer plug-load energy use. Integration with other energy-consuming systems such as lighting and HVAC, add to the opportunity to save energy in buildings. This could lead to developments such as an "Integrated Workstation Hub," which is an integrated occupant-driven environmental comfort and energy management system, all part of an occupant workstation.

6.2 Impacts of Collaboration to the United States and India

The project helped to identify areas where the cost of MELs energy-efficiency technology deployments could be reduced and ways to improve overall system efficiency from a whole-building perspective. It also provided a framework for development of a hardware and software platform, and for utilizing the collaborative mutual strengths shared by the U.S. and India. The project facilitated data exchange and innovation and facilitates new markets in both countries through collaboration. Further enhancements to the hardware and software infrastructure could make the smart plug strip an integrated workstation hub. Development of such integrated solutions will have applications in both countries to significantly reduce the energy use of MELs and improve costs. This collaboration between U.S and Indian companies has provided an impetus to aid new business opportunities and forge collaborative partnerships.

6.3 Next Steps

As a benefit to the U.S. business sector and/or technologies, the project findings, and the plug-load monitors and controllers evaluated can benefit from cost and design improvements by the U.S. manufacturer, which will facilitate their deployment in offices to reduce MELs energy use. With this vision, we propose the following key next steps:

6.3.1 Rules and Policies for Demand-Side Management

A key focus area is software to drive the intelligence for efficient use of MELs and its application for demand-side management strategies (e.g., efficiency or demand response). The software must target various levels of building operations (e.g., building manager, occupants) and interfaces (e.g., two-way information transfers to building automation systems and handheld devices). Such monitoring and control software is relevant to both new and retrofit buildings. The policies for this building energy automation would follow the hierarchy of default rules set by the corporate management and/or the building manager, which could further be individually configured by the occupants (under certain pre-set conditions). Such automation policies support "occupant-driven monitoring and controls" and enable their integration with other demand-side management strategies.

6.3.2 Interface with the Energy Information System and Integrated Office Hub

The Integrated Workstation Hub that interfaces MELs monitoring and control with local environmental monitoring and control (e.g., lighting, HVAC), the building automation system, and the building EIS will lead to increased adoption of MELs efficiency tools while also reducing implementation costs and enhancing energy-savings potential. Such interfaces will also enable integration of various end-uses for monitoring purposes and for understanding the relation between various end uses in a building.

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